energy and from electrostatic considerations alike, has now been shown to be fatal to the theory in any form.

If, therefore, we wish to adhere to the hypothesis that the connexion between solar outbursts and terrestrial magnetism is due to a projection of particles by the sun, we are driven to accept the view, which I have advocated for a long time, that the particles act by increasing the ionisation of the outer regions of the atmosphere and allow the electromotive forces which are always present locally to increase the intensity of the electric circulation. The rotation of the earth, which is the primary cause of the electromotive forces which come into play, then becomes responsible for the energy.

The view that the impact of the projected particles causes luminosity remains allowable, so that Prof. Birkeland's theory of the aurora borealis is still tenable.

On the Periodicity of Sun-spots.

By Arthur Schuster, F.R.S.

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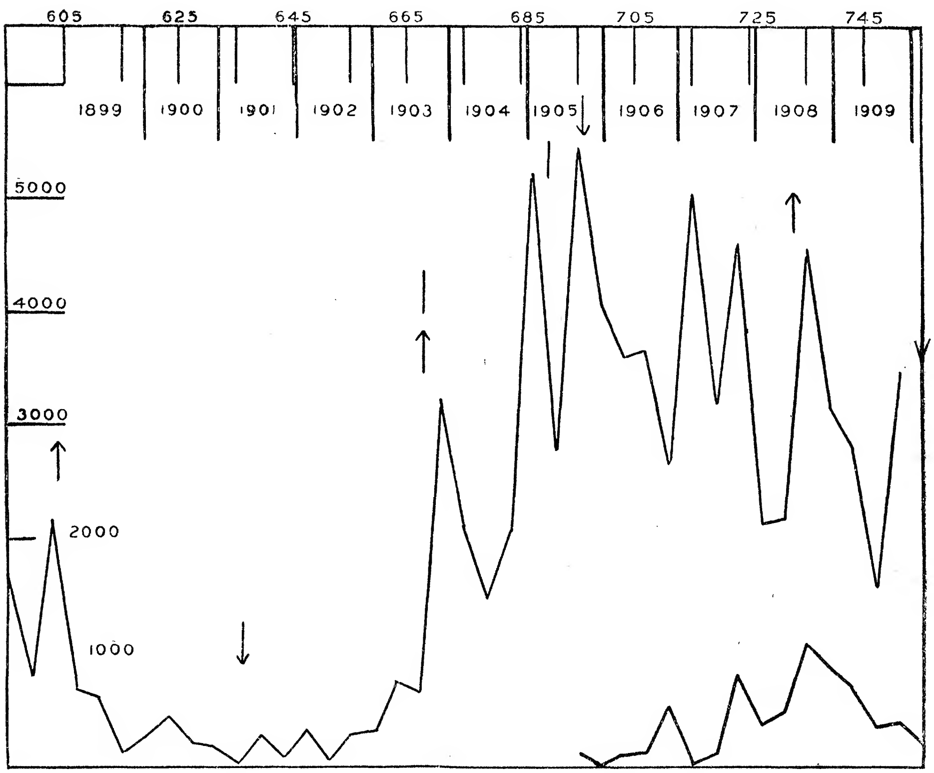
In the year 1906 I presented to the Royal Society an investigation* in which it was shown that the frequency of sun-spots was subject to recurrent variations, not only in the well-known 11 years' cycle, but also in other periods, which were determined. As we now possess additional material extending over 10 years, it is interesting to examine how far the minor maxima of the subsidiary periods can be traced in the more recent records. The accompanying figure gives diagrammatically the sun-spot areas measured at Greenwich between 1898 and 1909. The numbers plotted represent the sum of the mean areas during four successive rotations, beginning with the four rotations 593/596 of Carrington's series.

There is a period of 4·79 years, which in the previous communication was shown to be persistent during the whole time covered by sun-spot records, more persistent, in fact, than that of 11 years. I have marked on the diagram the predicted times of maxima of the period with an arrow pointing upwards. The first maximum, towards the end of the year 1898, which was timed to arrive during the rotation 604, actually took place three rotations, or about $2\frac{1}{2}$ months, earlier. The second maximum (September, 1903) was

* 'Phil. Trans.,' 1906, vol. 206, p. 69.

predicted to take place during rotation 668. It actually took place during the rotation 671, though an almost equally strong maximum was observed during rotation 667. We may therefore say that there is here an almost absolute coincidence in the predicted and observed times. The maximum of July, 1908, was delayed by about two months, but the activity had already risen considerably at the predicted time. In all three cases the coincidences of the predicted and actual times are very satisfactory, if it be remembered how variable is the observed maximum of the 11 years' period. This



periodicity of 4·79 years seems characterised by one or two sharp outbreaks near the time of the maximum, and throughout the time that accurate records are available it nearly always shows itself in each cycle as a separate peak in the curve representing sun-spot frequencies. The outbreaks of sun-spots connected with this period can be traced also in the magnetic records. There were several disturbances during September and October, 1898, notably one on September 9. In 1903 there was a magnetic storm on October 12, and more violent ones at the end of the month. Finally, in 1908, we had strong disturbances on September 11 and 29.

We must conclude that the previous evidence establishing this period has been further confirmed. In the meantime the same period has been discovered quite independently in the records of magnetic declination by Mr. Oppenheim.* Taking the average daily ranges for two successive years, as observed by Lamont in Munich during the years 1836—1886, Mr. Oppenheim, using a method differing essentially from that adopted by myself and others, comes to the conclusion that it is subject to a period of 4·92 years with an amplitude of about 12 seconds of arc. The difference between 4·92 and 4·79, as found by myself, is not important, considering that Mr. Oppenheim bases his calculation on a two-year mean and only 12 complete periods. This work being apparently undertaken in ignorance of the previous discovery of this period in the sun-spot records, the moral value of the confirmation it affords, is increased.

At the foot of the diagram I have represented the average rise and fall of this period as obtained from the mean of all observations extending over a range of 16 periods. The scale is that of the larger diagram, showing that the efficiency of this outbreak has been well above the average.

A period of 4·38 years, indicated as doubtful in my previous communication, receives no support by the additional material, though the evidence is not perhaps decisively adverse. The times at which this period should have reached its maxima are marked in the diagram by arrows pointing downwards.

A further periodicity of about 8·36 years, which appeared with considerable regularity between the years 1836 and 1887, has not since then shown itself. There should have been a maximum during the summer of 1904 at a time when there actually was a considerable diminution of activity.

A few words may be said on the apparently delayed maximum of the dominant periodicity of 11 years. The date of the maximum, as deduced from Fourier's analysis, differs from that found by observation, because the analysis picks out the simple period, while the observations include the harmonics. It is known that the sun-spot curve rises much more quickly before the maximum than it falls after it. The resulting curve, when analysed, gives the simple periodicity of 11 years, with a maximum later than the observed one, and it is the first harmonic which has its maximum coinciding with the observed maximum of solar activity. The true maximum of the 11 years' Fourier period should have taken place in 1905·35, but the greatest outbreak of spots which coincide with the maximum of the 5·56 year period was to be expected already in 1903·75. The times of these maxima are indicated in the diagram by lines drawn without arrow-heads.

* 'Met. Zeits.,' 1910, vol. 27, p. 270.

The first of them coincides with the maximum of the 4·79 period, and it is therefore open to us to ascribe this maximum to the 11 years' cycle rather than to the minor period. But in that case the subsequent behaviour of the activity becomes anomalous, as the spots ought to have diminished in number immediately afterwards. To judge from the appearance of the curve, it looks as if the two peaks in 1905 represent the true maximum of the 11 years' period, and that we must ascribe the outbreak in 1909 to some unknown cause. It was pointed out in my previous communication that the three well-established periods have periodic times which are sub-multiples of 33·375 years. It has often been remarked that the 11-year period shows particularly pronounced maxima during the first, third, and seventh decades, suggesting a periodicity of 33 years, and it is remarkable that this period can be traced in the Chinese records, reaching back to the beginning of our era.*

Though the last maximum was exceptional, in so far as it was rather below the average in intensity, the coincidence between the period of 33 years and the time of revolution of the Leonides meteorites is remarkable, and deserves careful attention. The delayed and disappointing display of Leonides at the end of last century is perhaps connected with the delayed and disappointing appearance of the last sun-spot maximum, while the exceptional brilliance of both phenomena 33 years previously is suggestive.

In the diagram the vertical scale represents sun-spot areas. Along the upper margin shorter lines are marked at intervals of 10 rotation periods, while the longer lines represent the divisions between successive years.

* 'Observatory,' 1906, vol. 29, p. 205.